Crop Adaptation to Climate Change

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Top right cover photo taken by Suvidya Yadav. In photo: Dr. Jens Berger (left), Ecophysiologist CSIRO, WA, Australia and Dr. Shyam S. Yadav (right) examining the Chickpea lines planted under the ACIAR-ICAR funded chickpea adaptation field trial at the Merredin Dryland Research Institute in Western Australia, Australia 2002.

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Under his leadership, the chickpea breeding team developed excellent material of both Kabuli and desi types. As a Program Leader of chickpea breeding team at IARI, he was successful in developing and releasing more than 20 high-yielding, widely adapted commercial chickpea varieties for different planting environments of India from 1988–2006. Some of India's pioneering and foremost chickpea varieties, namely, Pusa kabuli 1053, 1088, 1108, 2024, and Pusa Desi 362, 372, and 1103 were developed and released by him. Simultaneously, he also developed many unique germplasm lines that are being used in various national crop improvement programs by various chickpea breeders nationally and internationally. Dr Yadav has also guided many postgraduates students in the discipline of plant breeding on breeding approaches, methodologies, and techniques from 1990 to 2008. Dr Yadav served as Principal Investigator for various national and international research projects with Indian, Australian, and American research organizations during 1998–2006.

In 2002, he worked as International Legumes Consultant with the Food and Agriculture Organization (FAO) of United Nations in Myanmar. In 2007, he worked as International Technical Expert on standardization of quality products of fruit and vegetable crops for international marketing with United Nations Development Program (UNDP), Saana, Yemen. Later on in the same year of 2007, he was employed as Chief Scientist by Krishidhan Seeds Pvt. Ltd., Maharashtra, India. Then in 2008, he was employed as Chief Scientist and later on as Program Leader of Rice & Grains Program at National Agricultural Research Institute, Lae, Papua New Guinea. Thus, Dr Yadav has a wide working experience as an agriculture scientist, consultant, and expert in different countries across the continents ranging from Australia, United States, Asia, and the Pacific Region.

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He has published more than 125 research articles in various national and international journals. He is a Fellow of the Indian Society of Genetics and Plant Breeding, Indian Society of Pulses Research and Development, and The Linnean Society of London, UK. The current book on Crop Adaptation to Climate Change is Dr Yadav's fourth book as Chief Editor; prior to this he has edited *Chickpea Breeding and Management*, CABI, UK, 2007; *Lentils: An Ancient Crop of Modern Times*, Springer, The Netherlands, 2007; and *Climate Change and Management of Cool Season Grain Legume Crops*, Springer, The Netherlands, 2010.

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Dr Robert J. Redden completed a PhD in plant breeding and genetics at Cornell University, United States, in 1972. He was a postdoctoral fellow in the CIMMYT wheat breeding program from 1972 to 1974 with responsibility for introgression of spring wheat traits into winter wheat. He was a wheat specialist with IITA Nigeria 1975–1977 to assist with introduction of Mexican wheat into the national wheat program. Dr Redden transferred to the grain legume program at IITA headquarters in Ibadan for the period 1977–1981 with responsibility for the international cowpea breeding program.

Dr Redden was a breeder of *Phaseolus* for grain in Australia 1982–2000, mainly for small white "navy beans" and also lima and adzuki beans.

From 2001 to present, Dr Redden has been curator of the Australian Temperate Field Crops Collection, with responsibilities for cool season legume germplasm of pea, lentil, chickpea, faba bean and vetch, and for Brassica oilseeds.

Dr Redden has been an author for over 50 refereed articles over topics from biometrics, genetics, plant breeding, entomology, plant pathology, food science, and genetic resources. He has been a coeditor with Dr Yadav for publication of books on Chickpea Management and on Climate Change effects on Cool Season Grain Legumes, and has contributed chapters to books on lentil and on Genetic Resources of Grain Legumes.

Dr Redden has been a guest speaker at legume/climate change workshops with CIAT in both Tanzania and Cali.

In 2008, Dr Redden received the Yunnan Friendship Award for his leadership of two ACIAR legume projects with China.

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Foreword

Daniel Hillel and Cynthia Rosenzweig

A major task of our time is to ensure adequate food supplies for the world's current population (now nearing 7 billion) in a sustainable way while protecting the vital functions and biological diversity of the global environment. The task of providing for a growing population is likely to be even more difficult in view of actual and potential changes in climatic conditions due to global warming, and as the population continues to grow. Current projections suggest that the world's temperatures will rise 1.8–4.0°C by 2100 and population may reach 8 billion by the year 2025 and some 9 billion by mid-century, after which it may stabilize. This book addresses these critical issues by presenting the science needed not only to understand climate change effects on crops but also to adapt current agricultural systems, particularly in regard to genetics, to the changing conditions.

The natural "greenhouse effect" makes the temperature regime of some regions more hospitable to life forms than it would be otherwise. However, the progressive rise in concentrations of some atmospheric gases due to human activity (starting with the Industrial Revolution and accelerating during the most recent decades) poses the danger of excessive global warming. That rise is due mainly to combustion of fossil fuels (especially coal and petroleum), to clearing (often burning) of natural vegetation, and to enhanced decomposition of organic matter in cultivated soils. The primary culprit gases emitted are CO_2, CH_4, and N_2O. The accumulation of CO_2 has changed from the preindustrial value of 280 parts per million (ppm) to a level approaching 400 ppm—indeed a 40% rise!

Unless the emissions of greenhouse gases are curbed significantly, their concentrations will continue to rise, leading to changes in temperature and precipitation and other climate variables that will undoubtedly affect agriculture around the world. Changes in temperature to date have already begun to affect crops and farmers, with earlier spring growing seasons in Europe and North America, for example. These effects are projected to increase as climate continues to change.

Even though long-term projections suggest that temperatures will increase gradually, potential changes in climate variability—for instance, variations in the patterns of temperature and rainfall—can have profound impacts on food security. In near-term decades, higher CO_2 may provide some benefits to plant growth and water use, but these are likely to be offset by negative effects of rising temperatures and altered rainfall in the later decades of this century. Such impacts and their interactions will have region-specific and global effects on agricultural systems. The chapters in this book contribute to the understanding of the impacts of climate change variables and their progressive interactions that is critical to developing agricultural systems that will enhance productivity even in a changing climate.

The chapters included in this book are dedicated to the task of assessing the vulnerability of agriculture and adapting it to changing climatic conditions in the major agricultural regions of the world. Since the greater part of the projected population growth is expected take place in the less developed countries of Africa, as well as in parts of Asia and South America, and since climate change impacts are also projected to be more severe in low-latitude zones where many of the less-developed regions lie, the regional coverage of the volume provides much-needed information. An important criterion in future agriculture will be the selection of crops best adapted to the changing conditions, and their optimal management on a sustainable basis, in the diverse conditions in which agriculture is practiced.

As climate changes and populations continue to grow, production of food must increase by a commensurate amount just to maintain present nutritional levels, and by more than that if the diet in currently deficient regions is to be improved. The necessary improvement is not merely quantitative (i.e., measured in per capita consumption of calories, generally derived from starchy grain, tuber, or root crops). It should be qualitative as well (i.e., based on higher nutritional standards, likely to include the greater consumption of animal-derived protein). Advanced crop breeding that enhances genetics, environment, and management interactions as well as nutrition, as described in this book, is critical to developing the crop varieties needed to satisfy these multiple requirements.

Thus, the agricultural sector faces the significant challenge of increasing production to provide food security for the projected human population of 9 billion by mid-century, while protecting the environment and the functioning of its ecosystems. Therefore, scientists need to develop practices to mitigate climate change and adapt agriculture to the portending changes (to the extent that they cannot be avoided), so as to ensure adequate and nutritious production, along with protection of natural resources. The chapters in this book contribute to these crucial tasks.

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Foreword

M.S. Swaminathan

It is now widely accepted that climate change will be one of the greatest threats to sustainable food security. For example in India, even a 1°C rise in mean temperature will result in the loss of about 7 million tons of wheat. Sub-Saharan Africa and South Asia could be the regions that are worst affected by global warming. There is already an unacceptable prevalence of malnutrition, with FAO estimating that nearly 1 billion children, women, and men go to bed hungry every night. It is in this context that the present book by Dr Shyam S. Yadav and his colleagues is a very timely one.

Methods of mitigation and adaptation will have to .be standardized for every agroecological region. Agriculture can make a major contribution to mitigation through enhanced carbon sequestration and the building of soil carbon banks. Adaptation measures will vary according to the climatic characteristics of different ecosystems.

Therefore, it will be prudent to establish a Climate Risk Management Research and Extention Center in each agroclimatic zone. Such centers could develop drought, flood, and good weather codes in order to enable the local population to maximize the benefits of normal weather and minimize the adverse impact of unfavorable changes in temperature, precipitation, and sea level. Drought, flood, and good weather codes will have to be developed for each area indicating the steps we should take to minimize damage and maximize benefits.

Fundamental changes will be needed in breeding strategies. Both anticipatory and participatory research will have to receive much greater attention. Prebreeding centers that will help to develop novel genetic combinations for tolerance to biotic and abiotic stresses have to be established. Such prebreeding centers could take up participatory breeding work with farm families in order to combine genetic efficiency with genetic diversity.

Seawater farming is another area that needs attention since seawater constitutes nearly 97% of global water resources. An efficient method of converting seawater into freshwater is through the medium of halophytes. At MSSRF, Chennai, India, a Genetic Garden of Halophytes is being developed. Scientists of MSSRF have also transferred genes for seawater tolerance and for drought resistance from the mangrove *Aviccinia marina* and the fast growing and drought-tolerant shrub *Prosopis juliflora.* There are uncommon opportunities now for transferring genes across sexual barriers. In crops like wheat, which are sensitive to night temperature, we should shift the emphasis in breeding from per-crop to per-day productivity.

The book *Crop Adaptation to Climate Change* contains an extensive range of valuable papers. They will provide a road map for shaping our agricultural future in an era of climate change. I congratulate and thank Dr Shyam S. Yadav, Robert J. Redden, Jerry Hatfield, Hermann Lotze-Campen, and Anthony E. Hall for this timely contribution. I hope it will be read widely by all interested in promoting climate-resilient farming methods.

M.S. Swaminathan
Father of the Green Revolution in India
World Food Prize Laureate
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Foreword

Martin Parry

The threat to food security is probably the greatest challenge of climate change. The evidence is that, while there may be a few positive effects on yield potential in some parts of the world and for the initial two or three decades of warming, for the great majority of people, and especially as warming picks up after about 2030, the effect will be generally negative.

Moreover, the most substantial reductions in emissions—even if international action on mitigation were agreed—is not likely to avoid 2°C of global warming above preindustrial levels.

I am, therefore, very glad that Dr Shyam S. Yadav has brought together this team of experts and their writings on the effects of climate change on agricultural production. When I was editing the 2007 IPCC assessment on impacts, adaptation, and vulnerability, it became clear that our knowledge of potential effects on crops and livestock had advanced hugely over the preceding decade. There remained, however, very substantial gaps in our understanding.

Chief among these gaps in knowledge were the following: effects on crop yields in suboptimal conditions (such as low-nitrogen levels), especially in developing countries and in semiarid regions; effects on crop pests and diseases and their outcome for yield, and also on the competition from weeds; and effects on livestock carrying capacity and on direct animal well-being itself. Then there were the more upscale implications of altered yield and carrying capacity, such as the consequences of climate change on local, regional, and national food security. Finally, there were the uncertainties about what adaptive actions might be the most effective, from the plant level to the international level.

These issues are tackled in this volume. Its chapters report on recent progress in understanding effects on growth at the individual plant level, through to effects on the farm and village, to the implications for food supply locally and regionally.

I commend this book to readers as a fine example of the progress we have made and of the scale of the challenge ahead.

Professor Martin Parry, PhD, OBE

Formerly:
Co-Chair of Working Group II
(Impacts, Adaptation, and Vulnerability),
Intergovernmental Panel on Climate Change
(IPCC) until September 2008, team which
received the Noble Peace Prize for 2007.

Foreword

Ahmed Djoghlaf

This volume comes at a critical moment in the fight for a sustainable future. Today, we humans continue to drive species extinct at up to 1000 times the natural background rate. This rapid loss of biodiversity is undermining the stability of ecosystems across the planet and thereby threatening our own well-being. The ramifications of biodiversity loss become all the more worrisome when we factor in climate change. The degradation of many ecosystems is significantly reducing their carbon storage and sequestration capacity, leading to increases in emissions of greenhouse gases. Moreover, the relationship between biodiversity and climate change goes both ways: approximately 10% of species assessed so far have an increasingly high risk of extinction for every 1°C rise in global mean surface temperature, a trend that is expected to hold true up to at least a 5°C increase. Overall, 89% of fourth national reports received by the Convention on Biological Diversity (CBD) from its Parties indicate that climate change is either currently driving biodiversity loss or will drive it in the relatively near future.

These trends are particularly worrying when it comes to our food security, for agricultural biodiversity is now more threatened than ever. Seventy-five percent of the food crop varieties we once grew have disappeared from our fields in the last 100 years. Of the 7000 species of plants that have been domesticated over the history of agriculture, a mere 30 account for 90% of all the food that we eat every day. This loss of genetic diversity has potentially devastating consequences. For example, widespread failure in our handful of remaining major crops due to disease or pest outbreaks is a very real possibility: given that pest and pathogens are constantly evolving, a diverse gene pool is essential if we are to develop insect- and disease-resistant strains in the future. Moreover, our reliance on so few crops makes human populations that much more vulnerable to climate change: as growing conditions change, the most suitable species or cultivars in a given region may likewise change.

Agricultural biodiversity is extremely important because it provides humans not only with food but also with raw materials for many different goods—such as cotton for clothing, wood for shelter and fuel, plants and roots for medicines, and materials for biofuels—and with incomes and livelihoods, including those derived from subsistence farming. Agricultural biodiversity also performs ecosystem services such as soil and water conservation and maintenance of soil fertility and biota, all of which are essential to human survival.

Given the links between agricultural biodiversity and climate change, books that comprehensively address these links are sorely needed.

That is why the current volume is so important. With more than 100 contributors from all six continents, it offers a wide-ranging and in-depth look at the relationship between crop plants and climate change, making it an invaluable resource in our efforts to stabilize the climate, protect life on Earth, and thereby help safeguard the future well-being of our children.

Ahmed Djoghlaf
Assistant Secretary General
Executive Secretary of the United Nations
Convention on Biological Diversity

Foreword

Cary Fowler

Even the most conservative of climate change models give us a world later this century that is strikingly different than that in which we—and the crops that feed us—live today. And before then, plenty of dramatic change will already be upon us.

In many parts of the world, crops will face temperatures never experienced since the Neolithic: higher average temperatures, higher extremes, longer periods of dangerously hot weather, and high temperatures at important and vulnerable times in the plants' life cycle—and that's not to speak of fluctuations and variability in climate, more of which are a certainty in all the models; or changes and problems with water.

Crops have experienced climate change before, directly and indirectly, but never on this scale, never so rapidly, and never with the magnitude of impact we anticipate now. The historic movement of crops between continents, for example, constituted climate change "in effect" for many crops. But the challenge faced by maize in moving from Latin America to Europe and Africa 500 years ago was a very different one in time and magnitude than that which will confront maize in Africa in this century. Then, maize was not an established crop feeding hundreds of millions. Its rise as a staple in new lands proceeded in lock step with its adaptation and integration into farming systems. Today, climate change confronts humanity and its crops more pointedly and at a time when a billion people on earth are already hungry and vulnerable. It looms over both the most sophisticated and industrial and the most humble subsistence agricultural systems.

The central imperative of our time, I believe, is to get agriculture ready for climate change. Darwin unlocked the mystery of adaptation and evolution more than 150 years ago. He realized that diversity and inheritance, subjected to natural selection and time, led to evolution.

Though inheritance still works, time is certainly not on our side at this moment.

We have impressive amounts of crop genetic diversity at our disposal, however. It must be safeguarded and mobilized.

We have plant breeders and farmers to guide selection. They too must be safeguarded, mobilized, and significantly empowered.

Together, these are the ingredients for crop adaptation to climate change in the twenty-first century. This much is beyond dispute.

It would be folly to assume that our crops will magically become adapted to new and radically different conditions without substantial intervention and conscious action by human beings. It would also be folly to assume that our crops are somehow preadapted to what is coming. Our crops are domesticated. Their future is in our hands. There is no certainty.

Adaptation will not simply be achieved by hope or by policy decree. It will come crop by crop and region by region or not at all. The chapters in this book constitute an early and significant effort to specify what potential exists and what efforts and traits will be needed to ensure that agriculture is prepared to face its greatest challenge.

Cary Fowler
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Foreword

David K. Skelly

This volume represents a remarkable and greatly needed contribution to our response to changing climate. For at least two decades, the world's scientists have focused on communicating a phenomenon of global proportion. The scale of the policy challenges are enormous and, in many ways, unprecedented. It is no surprise, then, that there has been no rapid progress on developing a consensus about what may be done to halt or slow the drivers of climate change, let alone reverse it. As the world's governments continue what promises to be a drawn out process, there is much work to do.

The enclosed chapters provide an important model for needed research. It is perhaps no surprise that researchers working with crops readily appreciate that one size fits all solutions are unlikely to be useful. Yet the concept that adaptation will need to be customized for particular locations, let alone particular species, has escaped many commentators thinking about 'global' climate change. Research on crop adaptation can help us appreciate the difficulties in scaling down to the landscapes in which humans experience and respond to climate. At the same time, the past successes achieved by crop science provide a strong foundation for hope.

The research upon which these chapters are based, and the research that will be inspired by them, will have obvious direct benefits to human welfare. But there is perhaps a less appreciated dimension to this work. A very small number of researchers have been studying the potential for adaptation to climate change by wild species. There is tantalizing evidence that evolutionary responses are already taking place. But there are many skeptics who see such research as a distraction to the main job of alerting the public and decision-makers to the dangers of climate change. I believe research on crop adaptation will strengthen the case for expecting evolved responses in the natural world while also giving some of the clearest conceptions of how organisms can successfully cope with the altered conditions they are likely to experience as the world continues to change. In this and other ways, work on crops can inspire a range of audiences to move from hand wringing to action.

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Foreword

Walter P. Falcon

I am honored to have been asked to provide the foreword for *Crop Adaptation to Climate Change*. The authors are distinguished, the topic is timely, and the world is at a critical juncture with respect both to agriculture and climate. The foreseeable need to double agricultural output in a more populous, richer, and warmer world will surely challenge the best science that can be made available.

Agricultural and climate scientists will be eager to have this particular volume. It brings together the scholarly and gray literatures that typically reside on the multiple shelves of many bookcases. Having a single, well-documented volume, organized both by region and commodity, assures that it will be an invaluable reference for a wide range of scholars and practitioners.

While this collection of articles answers many of the questions at the intersection of climate and agriculture, it does not answer all of them. Nor should it be expected to. The understanding of crop physiology is still evolving, and even with a perfect understanding of the biology, economic, and political factors may condition what is feasible. Moreover, there are still very large uncertainties about future global change, especially with respect to several key variables. The stresses, and hence the adaptation needs, that key crops will be called upon to exhibit—and breeders and agronomists called upon to "fix"—must therefore also be uncertain.

Much of the general public is unaware of one fundamental source of variation about future climates. Predicting the broad dimensions of global climate change requires the use of complicated general circulation models (GCMs). These models are very large, often requiring more than 100 person-years in their development. There are more than 20 GCM models currently in use, and in general, they give broadly similar answers. However, at the regional, country, or subcountry levels—the geographic levels of most interest to agriculturalists—there can be large quantitative differences among projections from different models. (Many of the models also do not capture climate variability in very satisfying ways.) These differences among models are particularly important for projected rainfall patterns at downscaled country levels, which in turn have impact on the development of relevant adaptation strategies. They also complicate research comparisons when one group of scientists relies primarily on the output of a particular GCM, while other groups rely on alternative models. Fortunately, most of the chapters in this volume rely on an "ensemble" approach to GCM variation.

The GCMs are in much greater agreement on projected temperature changes, at least in terms of direction, than for rainfall patterns. While that is good news, the bad news is that many countries will exhibit substantially warmer temperatures over the next 50–100 years. Battisti and Naylor (2009), for example, show that for many parts of the world, the coolest years near the end of the twenty-first century will be warmer than the hottest years to date. And as several papers in this volume demonstrate, it is becoming increasingly clear that days above 30°C have serious consequences for grain yields—at least as plants are now configured.

More generally, breeders will likely be in frantic searches for the genetic variation required for the various crops as plants are pushed to the extremes of their growing ranges. This dilemma raises yet another set of questions: Will gene banks be prepared for the likely tasks ahead of them? Will wild relatives of crops be a likely source of such variation, and if so, by what processes can genes be isolated from these relatives and made available to breeders? And, will the search for genetic variation to accommodate climate change be instrumental in altering the debate about genetic transfers among species (GMOs)?

Crop Adaptation to Climate Change is not the first word on agriculture and climate, nor will it be the last. However, it provides important answers to a great many of the most pressing crop- and region-specific problems related to these topics. It is a very timely publication.

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Preface

Climate change is a reality in today's world and will exacerbate future attempts to support an increasing human population while not destroying the biosphere in the process. The Stern Review on the Economics of Climate Change in 2006 and the Fourth Assessment Report by the Intergovernmental Panel on Climate Change in 2007 have pushed the scientific and public debates on climate change a decisive step forward. It is now beyond doubt that anthropogenic greenhouse gas emissions are the primary cause for recently documented changes in climate, and that early, strong mitigation measures to decrease greenhouse gas emissions would eventually be more cost-effective than later adaptation to potentially catastrophic changes in climate. Substantial further changes in climate are likely to occur, however, even with aggressive mitigation efforts.

The human population is projected to increase from the current 7 billion to 9 billion within a period of only 40 years. Meeting the needs of these additional people will require substantial increases in production of agricultural systems using essentially the same area of arable land as is used today, or less due to expansion of cities. Current agricultural systems are to a certain extent adapted to current climates. Substantial changes in agricultural systems will be needed in the many regions subjected to critical changes in climate, especially if these systems are to have greater productivity.

Many of the world's poor live in arid and semiarid zones under environmental conditions that currently are challenging. In addition, these farmers do not have the resources to facilitate adaptation of their cropping systems to changing climates. Most developing countries are highly dependent on agricultural sectors strongly affected by climate change and have institutions with limited capacity to develop improved cropping systems. Consequently, a collaborative effort by the world's agricultural scientists is needed if the necessary changes to agricultural systems are to be made.

This book contributes to this collaborative effort by providing reviews by a group of international scientists with expertise in the principal crops grown in tropical and temperate zones. Projections are provided of the extent to which climate change will influence the productivity of these crops in different regions of the world. Opportunities for developing improved cropping systems adapted to future climates through plant breeding and changes in crop management are described. The goals of this book are: (1) to provide a blueprint to breed more resilient crops that can adapt to future climate change and also be more productive in sustainable cropping systems and (2) to encourage the political, institutional, and financial support needed for the doubling of agricultural production during this century.

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Acknowledgments

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The advice and suggestions of Professor Neil C. Turner, guidance from Dr T.J. Higgins, the former Deputy Chief Division of Plant Industry CSIRO, the enthusiasm and leadership of Dr Leanne B. Webb of CSIRO in identifying a team to assemble the viticulture chapter at short notice as substitute authors, the important contributions of Dr Andy Jarvis to many chapters as well as coordinating the regional chapter on South America, and the creative discussions with Dr Garry O'Leary for the local application of climate change modeling were all invaluable.

The editors extend their sincere thanks to the world renowned dignitaries Professor M. S. Swaminathan, Professor Walter Falcon, Dr Ahmed Djoghlaf, Professor David Skelly, Dr Daniel Hillel, Professor Cynthia Rosenzweig, Dr Cary Fowler, and Professor Martin Parry, who provided forewords for the book. The contribution of Professor Ted Wolfe is acknowledged in addressing the challenges of anticipating an uncertain future.

The editors express their sincere thanks to Mr. Manav Yadav, who was the Project Coordinator for this book. He has been working for this project right from the beginning when it was just a proposal until the final stages of the book publication. He managed the communications with editors, publisher—John Wiley and authors, and the technical editor queries. His dynamic leadership and commitment helped contributors involved to work on this project as a team and finished this daunting task in a timely manner.

We express our deep gratitude to several people who have rendered invaluable assistance in making this publication possible. Shyam S. Yadav and Robert J. Redden, Senior Editor and Co-Editor, respectively, express their appreciation for the late Dr Norman E. Borlaug, Noble Laureate, who inspired the professionalism and motivation for this book. Lastly, but not the least we express our special thanks to Justin Jeffryes, Anna Ehler, and Susan Engelken at Wiley-Blackwell Publishing, John Wiley & Sons, Inc., United States, for providing the technical and administrative support needed for publishing of this book.

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